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Issue Article

Denis Chemezov
Vladimir Polytechnic College
MEng, Honorary Worker of the Education Field of the Russian Federation, Academician of International Academy of Theoretical and Applied Sciences, Lecturer, Russian Federation
https://orcid.org/0000-0002-2747-552X
vpc-science@yandex.ru

Agannes Arzikyan
Independent Scientist
Vladimir, Russian Federation

Viktor Morozov
Yuryev-Polsky plant «Promsvyaz»
Technician-constructor, Yuryev-Polsky, Vladimir Oblast, Russian Federation

Egor Drozdov
Vladimir Polytechnic College
Student, Russian Federation

Viktoriya Golik
Vladimir Polytechnic College
Student, Russian Federation

Aleksandr Lukashov
Vladimir Standard LLC
Independent Scientist, Raduzhny, Vladimir Oblast, Russian Federation

Yaroslav Baranov
Vladimir Polytechnic College
Student, Russian Federation

Vladislav Samoylov
Independent Scientist
Vladimir, Russian Federation

Nikita Tatov
Vladimir Polytechnic College
Student, Russian Federation

THE EFFECT OF CASTING SPEED ON THE TEMPERATURE GRADIENT OF SOLIDIFYING MELT

***Abstract**: The results of modeling the casting process with numerical boundaries for changing the temperature gradient of a metal melt in a mold were presented in the article. It is determined that with a decrease in the casting speed, the temperature gradient in the melt volume has higher values than at high casting speeds. Thus, at low casting speeds, the solidification areas of the melt are narrowed.*

Key words: *casting, melt, liquid and solid phases, temperature gradient, casting speed.*
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Introduction

Various types of casting are used to produce blanks and/or finished products of complex configuration in mass production. The casting process is complex and the quality of castings is influenced by a number of factors (complexity of the mold, casting material, type of casting, temperature, etc.). The temperature of the metal melt plays an important role in the formation of the ingot during cooling and solidification [1-2]. The casting speed studied in this article characterizes the speed at which the melt is filled into the mold and thus determines the casting time. The temperature gradient determines the magnitude and direction of the heat flow. That is, knowing the values of the temperature gradient in the melt, it is possible to determine the temperature change per unit length [3-10]. Thus, local zones with a large temperature difference at the boundary of the transition from the liquid phase of the melt to the solid phase are predicted. This phenomenon is accompanied by the formation of casting defects in the casting. Thus, the aim of the study was to numerically calculate the values of the temperature gradient of the metal melt at different casting speeds and subsequent analysis of the results to form recommendations to engineers and technologists in the foundry.

Materials and methods

The process of cooling and solidification of the metal melt in the mold at casting speeds of 1.0 and 1.5 mm/s was simulated. The mold was a steel rectangle. The melt was poured into the mold at a temperature of 1473 K. The melt had the following properties: thermal conductivity – 200 W/(m×K), density – 8500 kg/m^3, ratio of specific heats – 1.0, dynamic viscosity – 0.0434 Pa×s. The simulated casting process was as close as possible to the real process by selecting the following parameters: temperature transition zone half width – 30 K, latent heat of solidification – 205 kJ/kg, heat capacity at constant pressure (solid phase) – 380 J/(kg×K), heat capacity at constant pressure (liquid phase) – 531.18 J/(kg×K), ambient temperature – 300 K, volume force damping constant – 0.001, volume force damping constant – 60000 kg/(m^3×s), heat transfer coefficient (mold) – 800 W/(m^2×K), heat transfer coefficient (air exposure) – 10 W/(m^2×K), surface emissivity (air exposure) – 0.8. The following modeling conditions were taken into account:

1. The equation of thermal conductivity in a liquid (density, heat capacity at constant pressure, thermal conductivity, velocity field at the interface of liquid flows, heat source and the ratio of specific heat capacities). Thermal conductivity describes the relationship between the heat flux vector and the temperature gradient, which corresponds to Fourier's law of thermal conductivity.

2. The equation of heat transfer with a phase transition. When the material reaches the phase transition temperature, the transformation takes place in a certain temperature range. In this interval, the phase of the material is modeled by a smoothed function representing the fraction of the phase before the transition.

3. The equation of laminar flow. The equation is used to calculate the velocity and pressure fields of a single-phase liquid flow in the laminar flow mode.

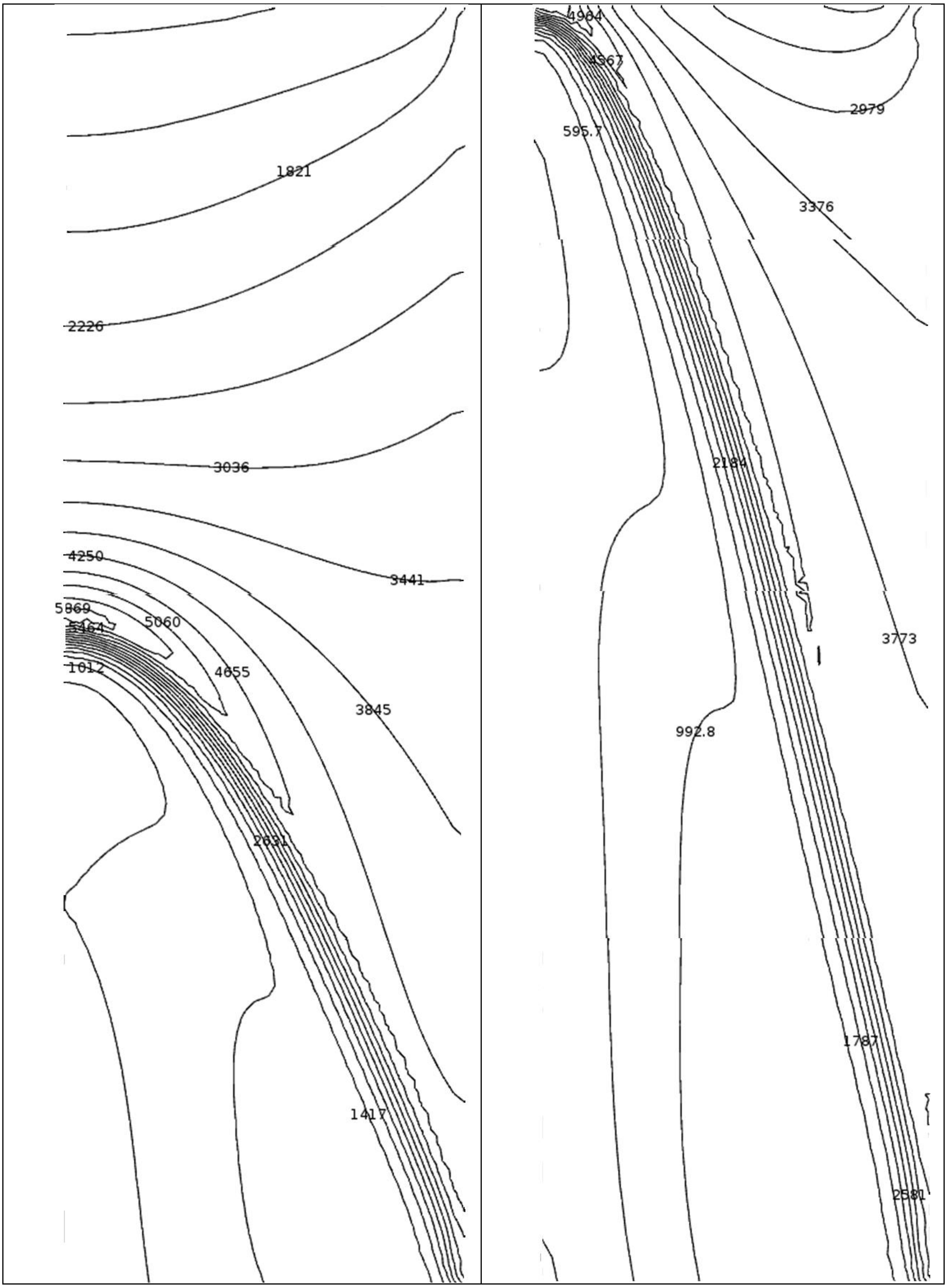
The simulation was performed in a two-dimensional formulation, so the visualization of the experimental results is represented by contours with randomized values of the melt temperature gradient.

Results and discussion

The contours of the temperature gradient of the metallic melt undergoing gradual cooling and solidification are shown in the Fig. 1. The contours were generated in a two-dimensional coordinate system, while filling the mold with melt was carried out from below. The calculated values on the contours are the values of the melt temperature gradient with a measurement unit of K/m.

The minimum, maximum and average melt temperatures at casting speeds of 1.0 and 1.5 mm/s were 806.98 K, 1454.78 K, 1176.42 K and 1062.83 K, 1466.13 K, 1339.98 K, respectively. Thus, the melt temperature at a casting speed of 1.5 mm/s is higher than at a casting speed of 1.0 mm/s.

The boundary defining the liquid and solid state of the melt is demonstrated by several identical contour dependencies with maximum temperature gradients of 5869 K/m and 4964 K/m at casting speeds of 1.0 and 1.5 mm/s, respectively. Thus, at the boundary of the melt transition from the liquid phase to the solid phase, zones of a significant temperature gradient are formed, which lead to a narrowing of the solidification range of the casting. Also, the contours in the figure show that the ratio of the liquid phase to the solid phase at a casting speed of 1.0 mm/s is 1:2, and at a casting speed of 1.5 mm/s is approximately 1:1.



A *B*

Figure 1. The temperature gradient (K/m) in the solidifying metal melt at casting speeds of 1.0 mm/s (*A*) and 1.5 mm/s (*B*).

Conclusion

Based on the analysis of the computer experiment, the following conclusions can be drawn:

1. The lower the casting speed, the lower the melt temperature in the mold. Low casting speeds lead to higher values of the temperature gradient at the boundary of the transition of the liquid and solid phases of the melt.

2. The ratio of temperature gradients between the transition boundary of the melt phases is greater at a casting speed of 1.5 mm/s. This means that more technological time is required for the solidification of the melt and, taking into account the thermodynamic effect, casting defects may form in the casting.

3. The phase transition process occurs almost proportionally in the volume of the melt at a casting speed of 1.5 mm/s.

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